Emerging Infectious Diseases in the United States

Improved Surveillance, a Requisite for Prevention

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INTRODUCTION

Once expected to be eliminated as a significant public health problem, infectious diseases remain the leading cause of death worldwide and a leading cause of illness and death in the United States.[1] As society, technology, and the environment change, pathogens can evolve or spread, altering the spectrum of infectious diseases. Emerging infections are those diseases whose incidence has increased within the past two decades or whose incidence threatens to increase in the near future.[2] Many factors or combinations of factors can contribute to disease emergence (TABLE 1). Newly emergent infectious diseases may result from the evolution of existing organisms; known diseases may spread to new geographic areas or new human populations; or previously unrecognized infections may appear in humans living or working in changing ecologic conditions that increase their exposure to insect vectors, animal reservoirs, or environmental sources of novel pathogens. Diseases may re-emerge owing to the development of antimicrobial resistance in existing agents (*e.g.,* gonorrhea, malaria, pneumococcal disease) or breakdowns in public health measures for previously controlled infections (*e.g.,* cholera, tuberculosis, measles).

Numerous examples demonstrate that emerging infectious diseases are a global problem (TABLE 2). In the United States, toxic shock syndrome and Lyme disease illustrate how new technology or products (super absorbent tampons) and changing ecology and human demographics (reforestation, increased deer populations, suburban migration), respectively, can foster the emergence of new microbial threats.[3,4] Other societal changes, such as our expanding use of child care facilities, have contributed to the emergence of infectious diseases that threaten children and staff in child care centers as well as other household members in infected children's

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TABLE 1. Factors in Emerge

Categories
Societal events
Health care
Food production
Human behavior
Environmental changes
Public health infrastructure
Microbial adaptation and change

[a] Adapted from reference 2.

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TABLE 1. Factors in Emergence[a]

Categories	Specific Examples
Societal events	Economic impoverishment; war and civil conflict; population migration
Health care	New medical devices; organ or tissue transplantation; drugs causing immunosuppression; widespread use of antibiotics
Food production	Globalization of food supplies; changes in food processing and packaging
Human behavior	Sexual behavior; drug use; travel; diet; outdoor recreation; use of child care facilities
Environmental changes	Deforestation/reforestation; changes in water ecosystems; flood/drought; famine; global warming
Public health infrastructure	Curtailment or reduction in prevention programs; inadequate communicable disease surveillance and diagnostic capacity; lack of trained personnel (epidemiologists, laboratory scientists, vector and rodent control specialists)
Microbial adaptation and change	Changes in virulence and toxin production; development of drug resistance; microbes as cofactors in chronic diseases

[a] Adapted from reference 2.

homes. Recent examples of child care-related infectious disease threats include *Escherichia coli* O157:H7, shigellosis, giardiasis, cryptosporidiosis, hepatitis A virus, and rotavirus.[5]

RECOGNIZING THE PROBLEM

Emerging infections such as acquired immunodeficiency syndrome (AIDS), Lyme disease, or hantavirus pulmonary syndrome and reemerging infections such as tuberculosis (TB) or cholera vividly illustrate that we remain highly vulnerable to the microorganisms with which we share our environ-

TABLE 2. Examples of Emerging Infectious Diseases, 1993

Inside United States
- *E. coli* O157:H7
- Cryptosporidiosis
- Coccidioidomycosis
- Multidrug-resistant pneumococcal disease
- Vancomycin-resistant enterococcal infections
- Influenza A/Beijing/32/39
- Hantavirus infections

Outside United States
- Cholera in Latin America
- Yellow fever in Kenya
- *Vibrio cholerae* O139 in Asia
- *E. coli* O157:H7 in South Africa and Swaziland
- Rift Valley fever in Egypt
- Multidrug-resistant *Shigella dysenteriae* in Burundi
- Dengue in Costa Rica and Panama
- Diphtheria in Russia

ment. Although many serious infectious diseases are preventable, current approaches to health care make effective control difficult.

Timely recognition of emerging infections requires early warning systems to detect new threats to health before they develop into public health crises. Prompt detection of these new threats depends on careful monitoring by modern surveillance systems and a thorough understanding of trends in incidence and distribution of known infectious agents. Better domestic and international surveillance systems to monitor these trends and detect emerging and reemerging infectious diseases are needed.

Surveillance of selected infectious diseases in the United States is based on state laws and regulations that require reporting of these diseases to health departments, generally by physicians or laboratories, to direct prevention and control programs. This notifiable disease system depends heavily upon voluntary collaboration between the Centers for Disease Control and Prevention (CDC) and state and local health departments, as well as those who report cases. However, reporting is generally incomplete, in part because of inadequate resources. Results from a recent survey by the Council of State and Territorial Epidemiologists (CSTE) further illustrate the inadequacy of existing infectious disease surveillance by documenting the limited number of professional positions dedicated to infectious disease surveillance in most states. For example, in 12 of the 50 states surveyed, no professional position is dedicated to surveillance of foodborne and water-borne diseases.[6] Also, no federal resources are provided to state and local health departments to support the national notifiable disease system in contrast to categorical disease programs such as those targeting AIDS, TB, certain cancers, and lead poisoning. In addition, the ability of state public health laboratories to support surveillance and control of infectious diseases has diminished, and health department services, such as insect vector and rodent control programs, have been dismantled in many states.

As highlighted in three recent reports by committees of medical and public health experts convened by the National Academy of Science's Institute of Medicine (IOM), the ability of the U.S. public health system and our health professionals to deal with emerging infectious disease problems is in jeopardy.[2,7,8] The earliest of these reports, published in 1987, "The U.S. Capacity to Address Tropical Infectious Disease Problems,"[7] documented our poor state of readiness to recognize, treat, or control infectious disease threats emanating from the tropics—regions which have yielded microbial threats such as cholera, Lassa fever, chloroquine-resistant malaria, and penicillin-resistant gonorrhea. The second report, "The Future of Public Health," published in 1988, concluded that the U.S. public health system is in disarray and emphasized that the U.S. approach to public health has too often been crisis-driven or reactive, a costly approach that limits the application of cost-saving preventive strategies.[8] The third IOM report, "Emerging Infections, Microbial Threats to Health in the United States," published in 1992, highlighted the ongoing threat to domestic and global health from emerging infectious diseases.[2]

TABLE 3. *Addressing Emergin*
States, Summary of Goals

Goal I	**Surveillance** Detect, promptly they cause, and
Goal II	**Applied Researc** Integrate laborato practice.
Goal III	**Prevention and** Enhance commun and ensure pro
Goal IV	**Infrastructure** Strengthen local, veillance and in

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[b] The CDC plan is entitled "*Ad*
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TABLE 3. *Addressing Emerging Disease Threats: A Prevention Strategy for the United States,* Summary of Goals

Goal I	**Surveillance** Detect, promptly investigate, and monitor emerging pathogens, the diseases they cause, and the factors influencing their emergence.
Goal II	**Applied Research** Integrate laboratory science and epidemiology to optimize public health practice.
Goal III	**Prevention and Control** Enhance communication of public health information about emerging diseases and ensure prompt implementation of prevention strategies.
Goal IV	**Infrastructure** Strengthen local, state, and federal public health infrastructure to support surveillance and implement prevention and control programs.

In collaboration with other federal agencies, state and local health departments, international organizations, academic institutions, and professional societies, CDC has developed a prevention strategy containing four goals that emphasize a multidisciplinary approach to the recognition and prevention of emerging infections (TABLE 3).[b]

The following discussion focuses on Goal I of this strategy and will highlight five important elements of improved surveillance for emerging infections: 1) strengthening the national notifiable disease system, 2) establishing sentinel surveillance networks, 3) establishing population-based emerging infections epidemiology and prevention centers, 4) developing a system for enhanced global surveillance, and 5) applying new tools and novel approaches to surveillance.

APPROACHING THE PROBLEM—IMPROVED SURVEILLANCE

To provide the vigilance and rapid response capability required to better detect, contain, and prevent emerging infectious diseases, improved surveillance systems must be developed. Surveillance serves several purposes: it permits disease patterns to be characterized by time, place, and person; detects epidemics; suggests hypotheses for epidemiologic investigation; evaluates prevention and control programs; projects future health care needs; and helps lower health care expenditures by facilitating earlier implementation of intervention strategies.[9,10] A well-functioning surveillance system is the most effective way to maintain vigilance for and ensure timely response to emerging infectious diseases. Because the ability to detect what is new or emerging depends on the capacity to know and track the routine, surveillance with appropriate laboratory support can function as an early warning system for emerging infections.

[b] The CDC plan is entitled "*Addressing Emerging Infectious Disease Threats: A Prevention Strategy for the United States.*" Copies may be obtained by writing to the National Center for Infectious Diseases, office of Program Resources-EP, Mailstop C-14, Centers for Disease Control and Prevention, Atlanta, GA 30333.

Many elements are required for effective surveillance. Information originates with someone in a hospital, laboratory, or clinic who detects a case, records it, and transmits the data needed for public health action to a local or state health department. Data from laboratories, hospital clinical records, or sources of vital statistics are often insufficient, and direct communication with patients or their health care providers may be required. At its origin, surveillance of infectious diseases must be thorough, and data must be recorded accurately and transmitted promptly. At each level of data collection, the quality of the information must be evaluated, and information from many sources must be combined and transmitted to the next level.

Data received through surveillance must be analyzed correctly, synthesized clearly, and disseminated effectively. The timeliness of this process is crucial to its efficacy. Each link in the surveillance chain must function well for the system to work. Most importantly, information gained through surveillance must lead to action by the public health system that includes investigating outbreaks, designing and implementing interventions, and evaluating the effectiveness of new or existing interventions. To accomplish effective infectious disease surveillance, the United States needs a national system that integrates laboratory and epidemiologic data. With effective surveillance, early identification of emerging infectious disease threats is more likely because problems can be recognized at any of several levels—at local or state health departments or at CDC, where national surveillance data are compiled and analyzed.

Modern society presents numerous challenges to surveillance. For example, assessing the health of under-served or transient populations, such as migrant workers, the homeless, or inner-city minorities, is difficult, but is extremely important because such populations are often most vulnerable to emerging infectious diseases. By targeting vulnerable populations for surveillance, opportunities for improved health care delivery and earlier recognition and containment of emerging infectious disease threats are enhanced. Likewise, infectious diseases that emerge abroad and threaten other nations through travel, immigration, and commerce challenge existing surveillance capabilities.

Strengthening National Notifiable Diseases Surveillance

The nation's notifiable disease surveillance system forms the foundation for our ability to know and track the routine. Certain infectious diseases—such as multidrug-resistant (MDR) TB, meningococcal meningitis, and botulism—warrant prompt detection of all cases because they cause substantial morbidity and mortality, require specific public health interventions, or may signal a potential outbreak. State public health authorities, other infectious disease experts, and CDC should reexamine currently reportable diseases, establish criteria for making a disease reportable, and explore ways to enhance rapid reporting of cases from clinical laboratories and health care practitioners. States must also examine the need to develop statutory requirements that

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clinical laboratories submit isolates of designated organisms of public health importance to the state laboratory. National infectious diseases surveillance must be flexible enough to include newer problems, such as *E. coli* O157:H7-associated hemolytic uremic syndrome (HUS), hantavirus pulmonary syndrome, or multidrug resistance in common pathogens (*e.g.,* pneumococcus, *M. tuberculosis*).

Enhanced surveillance for important food-borne and water-borne diseases, for example, is needed, including the addition of important emerging infections such as *E. coli* O157:H7 to the national notifiable disease system. Infectious agents continue to contaminate food sources and food-borne outbreaks of emerging infections are no longer isolated events involving only limited numbers of people. Evidence for these trends includes recent outbreaks of salmonellosis associated with the consumption of dairy products (domestic cheese, eggs); shigellosis associated with commercial airline food; and contamination of powdered milk products and infant formula with *Salmonella.*[11–17] In addition, in early 1993, hamburgers contaminated with *E. coli* O157:H7 and served at a fast-food restaurant chain caused a multistate outbreak of severe hemorrhagic colitis and hemolytic uremic syndrome, resulting in the deaths of at least four children.[18,19]

Water-borne outbreaks due to emerging pathogens may also be on the rise. In the spring of 1993, a municipal water supply contaminated with the intestinal parasite *Cryptosporidium* caused the largest recognized outbreak of water-borne illness in the history of the United States. An estimated 403,000 persons in Milwaukee, Wisconsin, developed prolonged diarrhea, and approximately 4,400 required hospitalization. (Personal communication: Jeffrey P. Davis, M.D., Communicable Disease Epidemiologist, Wisconsin, December 1993.)

In most areas of the United States, existing surveillance systems are inadequate to rapidly recognize outbreaks such as those caused by *E. coli* O157:H7 and *Cryptosporidium*. It is likely that improved surveillance and early recognition of these problems would prevent significant numbers of new infections through rapid investigation and institution of appropriate preventive interventions such as recalling hamburger contaminated with *E. coli* O157:H7 and issuing boil water advisories to interrupt transmission of *Cryptosporidium*. In addition, accurate disease surveillance can measure the effectiveness of regulations to ensure safe food and water.

National surveillance requires adequate infrastructure, including well-trained personnel within state health departments and local communities in addition to efficient and secure communications among CDC, state and local health departments, public and private laboratories, and health care providers. To establish a system that can effectively meet the threat of emerging infectious diseases, ties between these groups must be strengthened.

Establishing Sentinel Surveillance Networks

The use of sentinel events to enhance surveillance is an effective public health tool that has proven useful in the monitoring of many diseases. Sentinel

networks, linking groups of participating individuals or organizations to a central data receiving and processing center, have been particularly helpful in monitoring specific infections or designated classes of infections. Examples of such networks currently in use at CDC are the National Nosocomial Infection Surveillance (NNIS) system,[20] the National Respiratory and Enteric Virus Surveillance System (NREVSS), the Pediatric and Adult/Adolescent Spectrum of Human Immunodeficiency Virus (HIV) Disease Projects, and the domestic influenza surveillance network.

Expanded use of the sentinel network concept will improve our ability to detect and monitor emerging infections. With the cooperation of state and local health departments, CDC has proposed to establish a series of electronically linked Sentinel Surveillance Networks, organized according to information source, that will use novel and traditional data sources to compile information important to the assessment of emerging infections (TABLE 4).

Clinician or laboratory-based networks provide a mechanism for rapid interaction/consultation among members when unusual syndromes (*e.g.*, unexplained adult respiratory distress syndrome, idiopathic CD4 lymphocytopenia, or eosinophilia-myalgia syndrome) or laboratory isolates are detected. Networks of selected physicians' groups may also provide early warning of newly emerging syndromes of uncertain but probable infectious origin such as febrile diarrheal illnesses, meningitis and encephalitis, or hemorrhagic fevers. Such networks may also allow a more effective means for monitoring occupationally acquired infections in hospital and laboratory personnel. Other networks could focus on the emergence of drug-resistant pathogens (*e.g.*, clinical microbiology laboratories). Special consideration should also be given to the formation of veterinary networks to monitor established zoonotic diseases (*e.g.*, brucellosis, salmonellosis, cryptosporidiosis) or the increasing incidence of animal infections with zoonotic potential (*e.g.*, bovine tuberculosis, bovine spongiform encephalopathy).

Establishing Population-based Emerging Infections Programs

To complement and support local, regional, and national surveillance and research efforts, CDC has recently proposed that a network of population-

TABLE 4. Examples of Potential Participants in Sentinel Surveillance Networks

- Blood Banks
- Clinical Microbiology Laboratories
- Emergency Rooms
- Family Practitioners
- Gynecologists
- Infectious Disease Specialists
- Internists
- Medical Examiners
- Pediatricians
- Travel and Tropical Medicine Clinics

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based Emerging Infections Programs be established. The proposed programs will be developed through cooperative agreements with health departments and will be strategically located in sites across the country that offer access to various population groups. CDC will work with state and local health departments to establish these programs, building upon existing capacities and partnerships whenever possible. In turn, state health departments may choose to work with local academic institutions and other governmental or private-sector organizations to carry out program projects. The programs' purpose will be to forge strong links with local medical and public health personnel, and community representatives in order to establish continuous sources for population-based data as a foundation for conducting a variety of surveillance, epidemiologic, and prevention research projects relevant to emerging infections. These programs will also provide excellent opportunities for training public health professionals through cooperative arrangements between health departments, academic centers, and joint CDC/National Institutes of Health (NIH) training programs in infectious disease epidemiology.

In addition to providing population-based information, these programs will interact with special populations including the rural and inner-city poor; under-served women and children; the homeless; and immigrant or refugee groups. Other special population groups may also benefit from the proposed programs' activities. For example, an increasing percentage of our population is elderly or immunosuppressed, and a growing number of persons are immunosuppressed because of HIV infection, organ transplantation, or cancer chemotherapy. These population groups are at increased risk for emerging and drug-resistant infections, and their medical management is complex and costly. Specifically, these groups are highly susceptible to opportunistic infections, and an ever-expanding array of such infections is being seen in patients with AIDS and other forms of immunosuppression.[21]

Although their presence may facilitate the reporting of new infections or rare syndromes recognized by health professionals in the area, these programs are not expected to significantly improve our ability to actually detect previously unknown or unrecognized infectious diseases. Rather, they are designed to assess the public health impact of emerging infections and to evaluate methods for their prevention and control.

These population-based programs will provide a powerful tool for integrating information from many different places and sources, and about different emerging diseases. At the same time, national trends can be evaluated by combining information from the same project conducted at several programs across the country. Programs will maintain the necessary flexibility to accommodate changes in specific projects as the need for information changes. Some projects will be conducted at all programs, while others might be carried out in only a few (TABLE 5).

Priority activities will include:

1) Conducting active population-based surveillance projects to obtain detailed information about selected diseases for which adequate infor-

TABLE 5. Potential Projects and Locations for Emerging Infections Programs in the United States

POTENTIAL PROGRAM LOCATIONS	PROGRAM PROJECTS						
	Food-borne Disease Surveillance and Prevention (*e.g.*, *E. coli* O15:H7)	Opportunistic Infections in HIV-infected Inner City Populations (*e.g.*, MDR TB)	Drug Resistance in Nursing Homes and Child Care Facilities (*e.g.*, MDR Pneumococcal Disease)	Febrile and Diarrheal Illness in Migrant Farm Workers (*e.g.*, Malaria, Typhoid)	Unexplained Deaths of Possible Infectious Etiology in Young Adults (*e.g.*, ARDS)	Etiologic Agents in Community-Acquired Pneumonia (*e.g.*, *Mycoplasma*)
Northeast	X	X			X	
Mid-Atlantic	X	X	X		X	X
Southeast	X	X		X	X	
South	X	X		X	X	X
Midwest	X		X	X	X	
Southwest	X		X		X	X
West	X	X	X	X	X	
Northwest	X		X	X	X	X
U.S. Pacific Isles	X				X	X
U.S. Caribbean Isles	X	X			X	

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		X			X
	X	X	X	X	X

mation is currently unavailable, such as multidrug-resistant pneumococci and various food-borne infectious diseases.

2) Conducting special projects such as evaluating new diagnostic tests for Lyme disease; assessing illnesses that are often not specifically diagnosed but whose trends and etiologic information are important (*e.g.*, diarrhea, community-acquired pneumonia); and investigating the relationships between infections and chronic diseases (*e.g.*, hantavirus infections and hypertensive end-stage renal disease, hepatitis C and chronic liver disease).[22,23]
3) Conducting behavioral surveillance projects designed to assess trends in behaviors that either increase or decrease risk for infectious disease (*e.g.*, trends in food preparation and consumption practices, sexual behavior, travel, or exposure to animals).
4) Examining infectious diseases in the context of populations at risk, recognizing that the incidence of many emerging diseases will be highest among under-served populations and the immunosuppressed.
5) Implementing and evaluating pilot prevention and intervention projects for emerging infectious diseases that focus on safe food preparation in the home, handwashing in child care settings, appropriate use of antibiotics in clinical settings and in the community, and personal protection devices for clinical and laboratory personnel potentially exposed to infectious agents.
6) Providing technical assistance; epidemiologic, behavioral science, and laboratory expertise; and training to other agencies, institutions, or organizations in a Program's area when needed, such as during the investigation of outbreaks.

Developing Enhanced Global Surveillance for Emerging Infections

Although infectious disease threats often emerge in regions remote from the United States, they are readily transported here.[24–32] However, practical mechanisms for the early detection of such threats, such as international infectious disease surveillance systems, are rudimentary. Cholera provides an excellent example of the need for sound international surveillance capability. Cholera has recently returned to the Western Hemisphere in epidemic proportions after almost a century's absence (FIG. 1). Through October 1993, at least 900,000 cases of infection were detected and over 8,000 persons died. Although cholera initially reemerged in Peru, the disease has occurred throughout Latin America, and cases have been imported into the United States where more cases occurred in 1992 than in any other year since national cholera surveillance began in 1962.[15,25] Moreover, the *Vibrio cholerae* O1 strain responsible for cholera in Central and South America has been isolated from oysters and oyster-eating fish captured in oyster beds along U.S. Gulf Coast waters.[26]

More recently (1993), a newly described toxigenic strain of *Vibrio cholerae*, *V. cholerae* O139, has emerged in southern Asia where it is causing epidemic

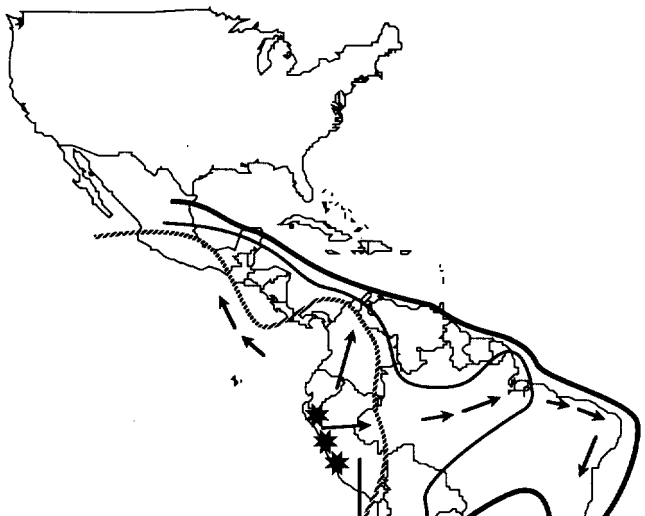

FIGURE 1. Spread of epidemic cholera—Latin America, 1991–1993.

cholera-like illness and has largely replaced *V. cholerae* O1 strains in many areas. Standard diagnostic tests for cholera are inadequate for this new strain, and neither currently formulated vaccines nor prior infection with *V. cholerae* O1 is protective. This new form of cholera is spreading, and an imported case has already occurred in a U.S. traveler returning from India.[27]

Effective approaches to surveillance on an international scale should include early detection capability and the capacity—national, regional, or international—to generate public health responses.[32] However, public health infrastructure and infectious disease expertise vary widely from country to country. Even in industrialized nations, a more timely and effective information exchange about emerging infectious disease problems is clearly needed.[33,34] For many developing countries, where this task will be the most difficult, established infrastructures, such as those in place for polio and

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in place for polio and

Guinea worm eradication efforts, and existing resources, such as those available from ministries of health, the World Health Organization (WHO), Institut Pasteur, the International Clinical Epidemiology Network (INCLEN), the U.S. Agency for International Development (USAID), the U.S. Department of Defense (DOD), NIH and CDC regional facilities or field stations, universities, and many other nongovernmental organizations, may be useful in efforts to improve international cooperation in detecting and evaluating emerging infectious disease threats.

Through enhancement and linkage of existing centers and networks, CDC has proposed that a global consortium of epidemiology and biomedical research centers be established to promote the detection, monitoring, and investigation of emerging infections. These centers would emphasize the integration of epidemiology and laboratory science. The consortium would be established in close cooperation with local ministries of health and operate under the direction of an international steering committee with representatives from CDC and other appropriate federal and international agencies or organizations. A central office for coordinating operations of the consortium, possibly at WHO, will be established. Initial steps would include review of the current and potential capabilities of various existing research facilities and surveillance systems, such as the WHO-sponsored arbovirus and hemorrhagic fever surveillance networks. Areas of expertise that are critical to meeting consortium goals of improved detection, monitoring, and investigation of emerging infections include epidemiology, clinical medicine (accompanied by ready access to patients and appropriate health care facilities), and laboratory sciences, particularly diagnostic microbiology. Expertise in related disciplines such as field ecology (*e.g.,* mammalogy, entomology) and behavioral sciences will also be important. To minimize startup costs and avoid lengthy delays, the highest priority for initial inclusion in the consortium would be given to facilities that currently maintain expertise in several of these disciplines (see TABLE 6).

The consortium members would assist their host countries by providing training and support to local and regional scientists and public health officials, aiding outbreak investigations in the region, and assisting with the formulation of public health policies. Laboratory and epidemiology back-up would be available from CDC and other collaborating organizations.

Applying New Tools and Novel Approaches to Surveillance

Infectious disease surveillance—both U.S. and global—should utilize modern computing and communications technologies to transform data into usable information quickly and effectively. Accurate, efficient data transfer with rapid notification of key partners and constituents is critical to effectively addressing emerging infectious disease threats. The systematic evaluation of new and innovative tools for the collection and analysis of epidemiologic data will enhance the speed with which technological, mathematical, and statistical advances are brought into use in efforts to better understand emerg-

TABLE 6. Examples of Potential Members of a Global Consortium of Epidemiology/Biomedical Research Programs/Centers

Existing Networks
- CDC Field Epidemiology Training Programs (FETPs)
- PAHO Polio Eradication Surveillance System
- International Clinical Epidemiology Network (INCLEN)
- International Office of Epizootics (OIE) Worldwide Information System
- WHO Arbovirus and Hemorrhagic Fever Collaborating Centers
- WHO Global Influenza Surveillance Network

Existing Research Facilities
- Caribbean Epidemiology Centre (CAREC), Trinidad
- CDC, National Center for Infectious Diseases Field Stations
- (Cote d'Ivoire, Guatemala, Puerto Rico, Kenya, Sierra Leone, Thailand)
- Department of Defense, U.S. Army and Naval Medical Facilities
- (Brazil, Egypt, Indonesia, Kenya, Peru, Philippines, Thailand)
- Food and Agriculture Organization of the United Nations (FAO) Reference Centers (Argentina, Brazil, Colombia, Czech Republic, France, Germany, Hungary, Kenya, Panama, Senegal, Spain, Sri Lanka, Thailand, UK, Uruguay, USA)
- French Scientific Research Institute (ORSTOM) (*e.g.*, Central African Republic, Congo, Cote d'Ivoire, Guinea, Senegal)
- Instituto de Nutricion para Centro America y Panama (INCAP), Guatemala
- International Center for Diarrheal Disease Research, Bangladesh (ICDDR,B)
- NIH, National Institute of Allergy and Infectious Diseases Supported Projects (Brazil, Colombia, Israel, Mali, Mexico, Philippines, Sudan, Uganda, Venezuela, Zimbabwe)
- Pasteur Institutes (*e.g.*, Algeria, Central African Republic, French Guiana, Iran, Madagascar, Morocco, New Caledonia, Senegal, Vietnam)

ing infections. Included in this process will be the appropriate evaluation and utilization of:

1) **Secure networks for the transmission of sensitive information.** Such networks are essential components of effective surveillance systems and should be designed to interface easily with national and international communications infrastructures for information dissemination and networking (*e.g.*, BITNET, INTERNET) being developed through the proposed High Performance Computing and High Speed Networking Applications Act of 1993.
2) **Automatic and direct reporting from physicians' offices, hospitals, and private and public laboratories.** Comprehensive health insurance and universal access to health care will facilitate this process and improve surveillance. Reporting would be received by state health departments as soon as cases are suspected or identified.
3) **Computer-based patient record technology.** Participation by public health professionals in the development of this capability is important to ensure that these systems are compatible with automated public health surveillance systems while maintaining patient confidentiality.

4) **Plans to integrat** INTERNET can mation exchange ways" for public h be modified to us data are stored i use interfaces.
5) **Geographic infor** GISs allow geogra tion to be visually These images and or other location Systems (accurate census data. This environmental cha eases.[35,36]
6) **New statistical a** New methodolog data from longitu applications to the cal models can be analyses, and may forecasting change ing or reemerging

This article has emp *Addressing Emerging Infe United States* (TABLE 3). approaches to surveillan availability, should provi emerging infectious disea

Emerging infectious water-borne *Cryptosporidi* borne *E. coli* O157:H7, as well as reemerging inf vividly illustrate that we r which we share our envi infectious disease threats lance systems. This artic surveillance for emerging

4) **Plans to integrate existing and planned information systems.** INTERNET can provide the physical framework for improved information exchange and the establishment of "information superhighways" for public health. Existing national surveillance systems should be modified to use common standards and protocols, ensuring that data are stored in compatible formats and retrievable via easy-to-use interfaces.
5) **Geographic information systems (GISs) and satellite imagery.** GISs allow geographically oriented information about disease distribution to be visually and analytically linked to images of the environment. These images and data can include satellite-generated images, housing or other location data obtained from hand-held Global Positioning Systems (accurate to less than a meter), digitized street maps, and census data. This technology may be particularly useful in monitoring environmental changes that could affect the emergence of infectious diseases.[35,36]
6) **New statistical and mathematical modeling methods.** New methodology for analyzing time-space clustering, GIS data, and data from longitudinal studies needs critical assessment for potential applications to the problems of emerging infections. Newer mathematical models can be used in both hypothesis-generating and confirmatory analyses, and may provide excellent opportunities for anticipating or forecasting changes in the incidence or distribution of important emerging or reemerging infectious diseases such as rabies.[37]

CONCLUSION

This article has emphasized the surveillance elements in CDC's plan, *Addressing Emerging Infectious Disease Threats: A Prevention Strategy for the United States* (TABLE 3). With this plan as a guide, implementation of these approaches to surveillance, based on public health priorities and resource availability, should provide a solid foundation for broader efforts to prevent emerging infectious diseases in this country.[38]

SUMMARY

Emerging infectious diseases such as prolonged diarrheal illness due to water-borne *Cryptosporidium,* hemorrhagic colitis and renal failure from food-borne *E. coli* O157:H7, and rodent-borne hantavirus pulmonary syndrome as well as reemerging infections such as tuberculosis, pertussis, and cholera vividly illustrate that we remain highly vulnerable to the microorganisms with which we share our environment. Prompt detection of new and resurgent infectious disease threats depends on careful monitoring by modern surveillance systems. This article focuses on five important elements of improved surveillance for emerging infections: 1) strengthening the national notifiable

disease system, 2) establishing sentinel surveillance networks, 3) establishing population-based emerging infections programs, 4) developing a system for enhanced global surveillance, and 5) applying new tools and novel approaches to surveillance.

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